TURBINE USER TECHNOLOGY NEEDS ASSESSMENT
SURVEY FINDINGS FINAL REPORT

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BACKGROUND

The Advanced Turbine and Engine Systems Product Team is currently planning for future program elements of sensors/controls/health monitoring (SCH) and Gas Turbine Power Plant Life Cycle Management (LCM). Technology from the SCH area supports the LCM program element as well as combustion, materials and vice versa.

NETL has an established relationship with turbine manufacturers and is well versed on their issues for the aforementioned program areas. The product team believes that turbine users may have different issues that also must be considered for inclusion in the program. The purpose of this task is to gather information about user issues related to life cycle management. NETL needs to understand the full scope of turbine issues, from both the manufacturer and user sides, in order to develop a program with maximum benefit to the public.

The gas turbine has evolved over the last several decades to dominate the aviation propulsion market. Continuing advances have significantly improved the durability of gas turbine designs and they are fast becoming the new power producers of choice in the world electricity market. At the present time, only about 15 percent of the world's installed electric generation capacity is gas turbine powered. The market for electrical power gas turbines has dramatically increased in the last decade. Today’s gas turbine designs offer record breaking high operating efficiencies; 40 percent for simple cycle units and almost 60 percent for combined cycle installations. These high efficiencies combined with their ready availability, low capital and operating costs, and clean combustion with a low level of pollutants have positioned gas turbines to become the dominant means of new electrical power generation worldwide.

Over the course of the next several decades, events in the global electric power market will be driven by the large future needs of much of the world's population, mostly in underdeveloped countries, and also by the global deregulation of electric utilities, which will tend to drive out less efficient power producers. Currently, the market for gas turbine-based electric power production applications is growing at more than 21% per year.

The key factors that will make future gas turbine power generation technology successful in the electric power generation and mechanical drive market segments are:

- Competitive economic performance (i.e., operating and life cycle)
- Commercial guarantees for performance and construction
- Reliable operation under a duty cycle of repeated startups and shutdowns
- Increased reliability and durability over current plants
- Fuel-switching capability
- Ability to meet regulatory emissions levels

SENSOR AND DIAGNOSTIC TECHNOLOGY STATUS

Current OEM Practice

Based upon the review of a Carolina Power and Light (CP&L) gas turbine peaking installation, the GE 7FA MFGQ (multi-fuel quiet combustion) units are equipped with a minimal instrumentation harness. The supplied sensors are adequate to assure safe operation and to monitor performance and emission requirements. These units are not equipped with any instrumentation, which would provide the ability to:

- Optimize performance
- Define risk of extending operating periods
- Monitor component degradation
- Provide early warning of faults in the system

The units are equipped with the following instrumentation:

- Continuous emission monitoring
- Turbine exhaust gas temperature (27 measurement points)
- Compressor pressure – inlet & outlet
- Compressor temperature – inlet & outlet
- Oil and natural gas fuel flow
- Combustion injection water flow
- Combustor flame sensors (3 measurement points)
- Bearing oil & metal temperatures - inlet & outlet (2 @ turbine & 2 @ generator)
- Vibration sensors at each bearing point (thrust & axial)
- Generator power output

The output from the instrumentation is acquired and used locally as input to the unit's control station. The control station consists of a PC equipped with GE software which provides the operator with a series of windows-based viewing screens which present the measured and calculated data, alarm status, etc. GE acquires the operating data from the units and transfers it by telephone to a central collection point at GE's Atlanta gas turbine service center. The data is then available for use by GE in tracking specific machine performance, for use in building empirical predictive formulas, for use in warranty related issues, etc.

Scheduled maintenance for the GE 7FA MFQC unit is specified by the manufacturer as follows:

Maintenance Procedure	Starts	Operating Hours
Combustor inspection	200 actual	Every 6000 actual
Hot gas path inspection	900 factored	every 24000 factored
Major inspection & repair	1800 factored	every 48000 factored
Turbine & compressor refurbishment	5000 factored	144000 factored

The factored starts and hours are determined by empirical formulas provided by GE. According to Mr. Mike Pollard of CP&L, the power industry is not completely comfortable with this approach and would prefer to have a more machine-specific condition-based approach to determining the timing of maintenance. Also according to Mr. Pollard, the power industry is experiencing higher than desirable maintenance costs for gas turbines and generally do not have confidence in GE's stated hot gas path component life and replacement interval.

Industry Technology Needs

The objective of this Turbine Users Technology Needs Assessment is to determine the future requirements of the user community regarding sensors, controls, condition/health monitoring systems, expert predictive systems, and turbine power plant life cycle management. This information would then be available for use in planning and directing future NETL program elements for the development of advanced technology to support the areas of (1) sensors, controls, and health monitoring and (2) gas turbine power plant life cycle management.

The areas of interest to the present assessment encompass a large technological scope. A significant amount of development effort has been conducted over the last decade by many researchers and is continuing. A comprehensive bibliography of gas turbine literature related to the pertinent areas of interest has been prepared and submitted in the Interim Report.

Vendors of existing land based instrumentation, as well as vendors of more advanced sensing systems, such as fiber optics, spectrometers, MEMS, pyrometers, acoustic techniques, etc., some of which have been applied in aerospace and other applications, are attempting to commercialize products for land-based gas turbines.

Sensors fall short in several categories. First, few alternatives based upon advanced technology have progressed to the point of commercial readiness to address some of the important plant operating issues, such as component life, component degradation, or risk associated with maintenance interval expansion. Second, it is difficult to apply existing sensor technology to robustly provide useful online input in the gas turbine environment, most notably in the combustion zone and gas turbine stages. Finally, the hardware and software are still at an early stage of development and the commercial application of many possible sensors and health monitoring systems is prohibitively expensive at this time.

Some of the unmet needs for turbine sensors and monitoring include:

- Component Life Monitoring either through direct or indirect monitoring of component properties.
  - ✓ On-line monitoring of component life would allow some assessment of when the next shutdown might occur.
  - ✓ On-line indication of component degradation could alert operators to failures that could propagate through the unit. For example, on-line monitoring of the combustor status or blade coating integrity would alleviate downstream consequences.
  - ✓ Off-line Non Destructive Evaluation (NDE) of component life would help determine if component replacements are needed before the next scheduled shutdown.
- On-line risk assessment of extending the outage schedule would also be useful to determine whether it is possible to operate for extended periods.
- Sensors that map the blades and vanes for integrity. For example, a temperature profile of the blades and vanes could indicate blocked cooling passages or coating failures.

There is a clear need for sensors and instrumentation systems which can operate in the turbine hot gas path and provide information to address the above issues. There is also a need for supporting software to interpret sensor and instrument outputs; correlate them to the machine's condition; provide the interpretative analyses; forward projections of servicing intervals; estimate remaining component life, etc. Thus, in addition to developing the basic sensor and instrumentation systems, there is a need to acquire long term data from sensors and instrumentation systems installed and operating in a commercial environment. These operating data will be necessary to complete the development of the sensors and instrumentation systems (i.e., develop robust commercial designs at acceptable cost) and build the data base from which to develop reliable predictive models.

From the manufacturer’s point of view, the needs outlined above are a secondary priority as compared to the machine design and evolution. Users, on the other hand, have to live with their units for 25-30 years. Consequently, their primary focus is on maintenance issues. Neither party alone is likely to commit the financial resources to address the above needs. Also, developing solutions to meet the needs is by its very nature a long-term proposition and requires data from many units operating over the entire commercial operating spectrum. There is clearly an opportunity for NETL to participate with sensor/instrument manufacturers, turbine manufacturers and utility users to implement a program to address the long term needs outline above.

Industry Technology Development Activities

In addition to the OEMs, there are several groups actively engaged in the development of technology which address various aspects of the areas of interest to the present NETL needs assessment. These various groups represent obvious potential collaboration partners for DOE. Formulating joint sensor and diagnostic development programs would leverage the R&D funding resources of the respective organizations. The following organizations have ongoing activities in the sensor, monitoring, diagnostic and expert systems areas:

- EPRI
- Combustion Turbine and Combined Cycle Users Organization (CTC^2)
- Propulsion Instrumentation Working Group (industry and federal agency collaboration)
- NASA
- DARPA

NEEDS ASSESSMENT SURVEY

A questionnaire was developed for the purpose of soliciting information regarding the needs for sensors, controls, health monitoring and expert systems from various gas turbine stakeholder groups. A copy of the questionnaire is included in Appendix A.

The questionnaire was distributed to selected end users and OEMs. Appendix B contains several lists of the various gas turbine stakeholders to whom the survey was sent. No completed survey responses were received from end users; however, survey responses were received from GE and Siemens Westinghouse. The responses from the OEMs are contained in Appendix C. In order to obtain end user input for the needs assessment, a series of telephone interviews were conducted with a number of end users. In addition follow-up telephone interviews were conducted with both GE and Siemens Westinghouse. Finally, telephone interviews were conducted with EPRI, CTC^2, Propulsion Instrumentation Working Group, and instrumentation manufacturers.

In addition to the above, information was obtained from Ms. Wickey Elmo of the Combustion Turbine and Combined Cycle Users Organization (CTC^2) regarding end users concerns. A summary of end user concerns received from Ms. Elmo is contained in Appendix D. Note that the information provided by Ms. Elmo was received from a survey conducted by CTC^2 of its member companies and in order to maintain anonymity of its member companies the respondents are not reported in Appendix D.

NEEDS ASSESSMENT FINDINGS

This section presents a summary of the information obtained from the various telephone interviews which were conducted. The following are the major finding of the Turbine Users Technology Needs Assessment:

- Electric utility users are very concerned with the gas turbine maintenance costs associated with the advanced gas turbine technology, which they are purchasing today. Since these machines do not have a fully established O&M track record electric utilities are facing an uncertain future maintenance cost environment. This financial risk is of particular concern for the electric utilities as they leave a regulated business environment and enter a new competitive business environment. In the future electric utilities will not be able to readily pass unanticipated O&M costs through to the consumers through a mandated rate change. In the competitive environment unforeseen maintenance costs will come out of operating profits which will have negative impact for the utility management and stockholders.

- Electric utilities are a good source of what kinds of operational and maintenance problems are being encountered today for both older generation gas turbines as well as for the current and new generations of advanced gas turbines. There are varying degrees of understanding of the detailed design issues of gas turbine technology among the electric utility community. Utilities are focused on the operation and maintenance of gas turbine systems, and as such do not retain staff skilled in the fundamentals of gas turbine technology. Their in depth knowledge of detailed system design details and fundamentals underlying the design are limited to what they need to know from an operational and maintenance perspective. Beyond that they rely on the OEMs for support and answers to problems encountered in operations. As such, electric utility personnel are not the best source for determining specific monitoring and diagnostic technology, which should be incorporated in future, gas turbine technology.

- Each new class of gas turbine technology undergoes a long slow evolutionary design process, which starts with prototype testing in the OEM's development and demonstration facilities and continues throughout the commercial life of the gas turbine class. Over the life of any class gas turbine, the OEM will introduce both system operational design changes as well as component design changes to improve overall system performance, reliability and durability. Over a long period of time the OEM will introduce a series of component design changes, modifications and upgrades which are implemented in response to problems which are encountered in the commercial fleet operation. The time scale for this process is on the order of several decades and is characterized by a significant number of problems occurring in the initial years after introduction with the frequency of new problems declining as the design approaches its end of life. By way of example, the GE E class gas turbine design is approximately 28 years old, its design is fixed and users report the design to be relatively trouble free with the O&M costs reasonably understood and predictable. By contrast, the GE F class gas turbine design is approximately 15 years old, its design is still undergoing significant operational and design changes and user report design, operational and maintenance problems with the O&M costs not fully understood for the most recent design improvements which have been implemented.

- There is clearly a move within the electric utility industry to transfer the risks associated with the advanced gas turbine systems back to the OEM through long term maintenance contracts. The utilities recognize that the current generation gas turbine designs are still in a stage of flux and will continue to evolve until the O&M problems are fully resolved. The most significant system operational change has been the gradual increase in the firing temperature which are now approaching 2500 ^{o}F. This is probably the single most important operating variable associated with component life and durability issues. The electric utilities believe that it will be some time before the OEMs are able to produce hot gas path components that are capable of achieving a good service life expectancy.

- OEMs recognize that they are experiencing a bubble in new gas turbine demand. They recognize that their long-term income will come through maintenance revenues. They are well aware that the adoption of the next generation of gas turbine technology will be dependent upon the electric utilities comfort level in understanding and controlling their O&M costs. In the deregulated environment the availability and maintainability of gas turbine systems which are being operated at the cutting edge of technology become very significant cost issues. OEMs recognize that there is an opportunity to meet the electric utility needs through long term service agreements. These service agreements will require the OEMs to provide for both unanticipated outages as well as routine maintenance. OEMs will be required to implement more sophisticated sensor and diagnostic technology, which will provide for early warning of fault conditions in order to avoid catastrophic failures. Also advanced technology will be required in order to migrate from rule based maintenance to condition based maintenance. Condition based monitoring which supports just-in-time maintenance offers the potential for reducing long-term maintenance costs and improved profitability of the electric utilities. OEMs are clearly moving in this direction.

- There has been and continues to be a considerable amount of effort within the aero-derivative gas turbine community to develop sophisticated sensor and diagnostic technology which can be integrated into and support a condition based maintenance framework. This technology is directly transferable to electric utility gas turbine systems. This is clearly a source of technology that can and should be leveraged. The introduction of new technology into the propulsion application as well as the power application is a slow process leading to final acceptance. In general new sensor and diagnostic technology enters the market through application to military aircraft where the higher cost for development and procurement can be borne. Once the technology is proven for the military application and the cost for production hardware begins to fall, the technology is positioned to migrate to the commercial aircraft application. As technology achieves recognition in the aircraft application it is then positioned to enter the power generation application. By way of example, consider the use of pyrometry for real-time examination of turbine blade surface temperatures. According to Land Pyrometer this technology has been under development for use on military gas turbine engines for approximately 25 years. Currently they have commercial units installed on approximately 6000-7000 fighter aircraft engines. They are now just closing on the first orders for commercial aircraft applications. Currently Land Pyrometer is actively investigating the application of pyrometers to electric power gas turbines with GE, EPRI and others. Commercial use on electric gas turbine application is several years away.

- From the OEM's point of view, the need to reduce maintenance costs has been a secondary priority as compared to the machine design and evolution. From an electric utility's perspective, it is going to live with the unit for 25-30 years and hence it has a primary focus on the maintenance issues. Neither party is likely to independently commit the financial resources to address the needs alone. Also, developing solution to meet the needs is by its very nature a long-term proposition and requires data from many units operating over the entire commercial operating spectrum. There is clearly an opportunity for NETL to participate with sensor/instrument manufacturers, turbine manufacturers and utility users to implement a program to address the long term needs to support better diagnostics and condition based maintenance. Given the competitive business environment that electric utilities are entering, without the development of conditioned based monitoring technology to support the advanced gas turbine technology the adoption and introduction rate of the technology will be slow.

- There is a clear need for sensors/instrumentation systems which can operate in the turbine hot gas path and provide information to address the many issue areas which result from extending the gas turbine firing temperature to higher levels. In addition to the base sensor/instrument there will be a need for supporting software to interpret sensor/instrument output, to correlate it to the machines condition and to provide the interpretative analysis and forward projections necessary for predicting servicing intervals, life remaining, etc. This suggests that in addition to the basic sensor/instrument development there is a corresponding need to install and acquire long term data from the sensor/instrument installed and operating in the commercial unit environment. This operational data will be necessary in order to complete the development of the sensor/instrument (i.e., develop a robust commercial design with an acceptable cost) as well as to build the data base from which to develop the ultimate predictive models (e.g., time remaining until service, component remaining life, etc.).

CONCLUSIONS

Based upon the findings from this Needs Assessment, the following conclusions have been reached:

- There are several major unmet gas turbine sensor needs associated with measurements of conditions in the hot gas path:
  - ✓ combustion pressure pulsation
  - ✓ turbine circumfrential inlet temperature distribution
  - ✓ turbine blade surface temperature
  - ✓ turbine blade vibration
  - ✓ turbine blade tip deflection
  - ✓ stator vane bowing

- There is a need for component life monitoring through direct or indirect measurements of:
  - ✓ component operating conditions (on-line)
  - ✓ component physical properties (on-line & off-line)

- There is a need for off-line NDE techniques to determine if component replacement is required before next scheduled inspection.

- There is a need for NDE measurements & supporting analysis to determine:
  - ✓ component physical condition referenced to baseline
  - ✓ component cyclic fatigue status
  - ✓ component coating wear & integrity status

- Condition & health monitoring technology:
  - ✓ is in the early stages of development
  - ✓ will requires advanced sensor technology
  - ✓ requires extensive components & system operational data for validation

- Computer based gas turbine condition & health monitoring predictive systems offer the potential for:
  - ✓ reduced nuisance shutdowns & unplanned outages
  - ✓ optimum engine operation
  - ✓ continuous real-time maintenance scheduling
  - ✓ extended time between overhauls based upon determination of remaining component life
  - ✓ protection against catastrophic failure via real-time fault assessment

- One approach NETL could use to address the unmet sensor needs is:
  - ✓ review existing & emerging developmental instrumentation technology
  - ✓ select the most promising technology
  - ✓ adapt technology for use in commercial power plant environment
  - ✓ install, operate, refine & field validate technology

- One approach NETL could use to address the unmet expert systems needs is:
  - ✓ review emerging expert systems
  - ✓ determine the supporting sensor requirements
  - ✓ select the most promising expert systems
  - ✓ field validate the expert systems

APPENDIX A - SENSORS, CONTROLS, HEALTH MONITORING & EXPERT SYSTEMS QUESTIONNAIRE

On behalf of the Department of Energy's Office of Fossil Energy, the National Energy Technology Laboratory (NETL) is implementing a program to support the development of the Next Generation Turbine Systems. The NETL is developing a comprehensive strategy, which will address the full range of advanced technology required by manufacturers and users of these advanced turbine systems. In support of the development of a strategic plan, the NETL Advanced Turbine & Engine Systems Product Team is currently planning for future program elements in the areas of sensors, controls, health monitoring and expert systems and is seeking to obtain input from a diverse cross section of stakeholders from the gas turbine community regarding the technology needs in these areas.

We are interested in establishing the future technology needs for sensors, controls, health monitoring and expert systems which will be needed to ensure highly reliable Next Generation Turbine Systems which operate at optimum efficiency and low NOx emissions. Depending upon the end-use application (i.e., base load operation, intermittent operation, peaking operation) and the power range, anywhere from 60 to 85% of the failures experienced by today's gas turbine systems are encountered by components which are located in the hot gas path. Consequently, our current needs assessment will be focused on the gas turbine subsystems and components, which are associated with the machine's hot gas sections.

While our primary focus is on gas turbines for electric power generation, we recognize that the needs for the supporting technology elements of sensors, controls, health monitoring and expert systems technology can be quite similar for gas turbines designed for different end-use applications. We are therefore interested in obtaining your input covering the major end-use applications, including stationary electric power generation (base load and peak load); aircraft propulsion; mechanical equipment drive (e.g., gas compressor); and marine propulsion.

The accompanying table provides a list of the gas turbine hot gas section subsystems and components for which we are seeking to develop an understanding of the state-of-the-art and the future needs for the supporting technology elements. This information is being sought for (1) on-line real-time operational parameter measurements, and (2) out-of-service inspection and examination measurements. As part of the survey, we are interested in assessing the likely commercial development and deployment time horizon for supporting technology needs characterized as (1) Short Range (less than 3 years), Mid Range (3 to 7 years), or (3) Long Range(7+ years).

Relative to the elements of the accompanying table, we are seeking input from gas turbine stakeholders which will allow us to address the following:

1. What is the current best practice in use today for sensors, controls, health monitoring and expert systems? Who are the suppliers? Where do these elements fall short? How can they be improved?

2. For the subsystems and components listed in the table, what are the major field problems which gas turbine users encounter relative to turbine operating performance, availability, duty cycles, performance-based planned maintenance and life cycle management? For any specific problems identified, please provide detailed information regarding the problem (e.g., turbine subsystem and component, accumulated operating hours, nature of problem or failure, etc.); the power plant configuration (e.g., simple cycle, combined cycle, etc.) and the turbine power system (e.g., model, age, end-use application, power output, etc.). What are the unmet needs for sensors, controls, health monitoring & expert systems to provide for early detection and avoidance of these problems?

3. Regarding gas turbine system performance measurement, diagnostic monitoring, and expert analysis & predictive tools what are manufacturers and other suppliers offering for use with current generation turbine power plant systems? What are they planning to offer in their next generation turbine systems? What do end users want?

We would appreciate any information which you could provide for the various subsystems and components identified. Also any referrals to other individuals in your organization who could provide us with information would be appreciated. If you have any questions please direct them to the contact identified below. Thank you in advance for your participation in this needs assessment.

Questions and responses to this needs assessment should be directed to:

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GAS TURBINE SUBSYSTEM	GAS TURBINE SUBSYSTEM COMPONENT	TECHNOLOGICAL IMPROVEMENTS			SUPPORTING TECHNOLOGY NEEDS					TIME HORIZON
		DESCRIPTION OF DEVELOPMENT ACTIVITY	DEVELOPMENT STATUS	END-USE APPLICATION	CONTROLS	ON-LINE MEASUREMENT & MONITORING		SHUTDOWN INSPECTION & MEASUREMENT		
						SENSORS	HEALTH MONITORING	SENSORS	HEALTH MONITORING	
COMBUSTION	Dual Fuel Capability									
	Fuel Nozzle									
	Catalytic Combustion									
	Combustion Can Cooling									
	Combustion Liner									
	Crossover Tubes									
	Transition Section									
TURBINE	Nozzle Section									
	Blade Material									
	Blade Protective Coatings									
	Blade Cooling									
	Blade/Casing Gap									
	Disc									
OTHER	Bearings-Radial									
	Bearings-Thrust									
	Seals									
	Lubrication									
	Exhaust Emissions									
EXPERT SYSTEM SUPPORT APPLICATIONS	Operational Process Control									
	Interrogation for Fault Detection									
	Accumulated Damage Analysis									
	Remaining Life Prediction									
	Probability of Failure Prediction									
	Life Cycle Management									

Notes:

End-use application
EPB - electric power, base load generation
EPL - electric power, peaking operation
AP - aircraft propulsion
MD - mechanical equipment drive
MP - marine propulsion

Time horizon
SR - less than 3 years
MR - 3 to 7 years
LR - 7+ years

APPENDIX B - SURVEY RECEIPENTS

Initial Survey Contacts

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Westinghouse 501 Turbine Users

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APPENDIX C - OEM SURVEY RESPONSES

General Electric Response

Subsystem	Component	Technology Improvements: Description	Technology Improvements: Status	Technology Improvements: End Use	Supporting Technology: Controls	Supporting Technology: On-Line Measurement: Sensors	Supporting Technology: On-Line Measurement: Monitoring	Supporting Technology: Shutdown Inspection/Measurement: Sensors	Supporting Technology: Shutdown Inspection/Measurement: Monitoring
Combustion	Dual Fuel Capability	Liquid Fuel Carbon Buildup	MR	EPB		Flame Profile, flame detection			
	Fuel Nozzle	Pre-mix Flame Stability	MR	EPB	Active	Flame Profile, robust dynamic pressure transducers		Material Integrity	Yes
	Catalytic Combustion	Catalyst Durability	MR	EPB		NOX Optical	Yes		
	Combustion Can Cooling	None							
	Combustion Liner	Uniform Temperature Distribution	MR	EBP		Hot Spot Detector	Yes	Electronic Metrology	Yes
	Crossover Tubes	Continuous Crossfire Temperature Detection	SR	EPB		Temperature Switch		Crack Detection	Yes
	Transition Section	Uniform Temperature Distribution	MR	EPB		Hot Spot Detector	Yes	Coating Thickness Crack Detection	Yes Yes
Turbine	Nozzle Section	Extended Life	SR	EPB		Gas Temperature Metal Temperature	Yes Yes	DZG	Yes
	Blade Material	Extended Life	MR	EPB		Gas Temperature Metal Temperature	Yes Yes	DZG	Yes
	Blade Protective Coatings	Hot Spot Detection Oxidation Resistance	SR	EPB		Surface Temperature	Yes	Coating Thickness NDE	
	Blade Cooling	Temperature Profile Anomaly	SR	EPB		Pyrometry	Yes		
	Blade/Casing Gap	Efficiency Creep Detection	MR MR	EPB EPB		Clearance	Yes	Clearance	Yes
	Disc	Extended Life	MR	EPB	Active	Surface Temperature	Yes	UT(if Needed)	Yes
Other	Bearings-Radial	Reliability	SR	EPB/EPL		Alignment	Yes		
	Bearings-Thrust	Reliability	SR	EPB/EPL		Load Cells	Yes		
	Seals	Efficiency	SR	EPB				Clearance	Yes
	Lubrication	Reliability	SR	EPB/EPL		Viscosity PH	Yes Yes		
	Exhaust Emissions	Environmental Compliance	MR	EPB	Active	NOX Optical	Yes		
Expert Systems Support Applications	Operational Process Control	Model Based Optimization	MR	EPB	Active	Fuel LHV	Yes		
	Interrogation for Fault Detection	HGP Prognostics-Reliability	MR	EPB			Yes		
	Accumulated Damage Analysis	Deterioration Signatures	LR	EPB				Grain Boundary Creep	Yes
	Remaining Life Prediction	Material Characterization	LR	EPB		Smart Sensor Taggents	Yes	Robotic NDE	Yes
	Probability of Failure Prediction	Operational History & Models	LR	EPB					
	Life Cycle Management	Asset Optimization Modelling	MR	EPB		Smart Sensor	Yes	(Component Inspections)	

Notes:

End-use application	EPB - electric power, base load generation
	EPL - electric power, peaking operation
	AP - aircraft propulsion
	MD - mechanical equipment drive
	MP - marine propulsion
Time horizon	SR - less than 3 years
	MR - 3 to 7 years
	LR - 7+ years

Siemens Westinghouse Response

GAS TURBINE SUBSYSTEM	GAS TURBINE SUBSYSTEM COMPONENT	TECHNOLOGICAL IMPROVEMENTS: DESCRIPTION OF DEVELOPMENT ACTIVITY	TECHNOLOGICAL IMPROVEMENTS: DEVELOPMENT STATUS	TECHNOLOGICAL IMPROVEMENTS: END-USE APPLICATION	SUPPORTING TECHNOLOGY NEEDS: CONTROLS	ON-LINE MEASUREMENT & MONITORING: SENSORS	ON-LINE MEASUREMENT & MONITORING: HEALTH MONITORING	SHUTDOWN INSPECTION & MEASUREMENT: SENSORS	SHUTDOWN INSPECTION & MEASUREMENT: HEALTH MONITORING	TIME HORIZON
COMBUSTION	Dual Fuel Capability					X	X			
	Fuel Nozzle					X	X	X	X	
	Catalytic Combustion					X	X			
	Combustion Can Cooling					X	X			
	Combustion Liner									
	Crossover Tubes					X	X			
	Transition Section					X	X	X	X	
TURBINE	Nozzle Section					X	X	X	X	
	Blade Material					X	X	X	X	
	Blade Protective Coatings					X	X			
	Blade Cooling					X	X			
	Blade/Casing Gap									
	Disc									
OTHER	Bearings-Radial									
	Bearings-Thrust									
	Seals									
	Lubrication									
	Exhaust Emissions					X	X			
EXPERT SYSTEM SUPPORT APPLICATIONS	Operational Process Control					X	X			
	Interrogation for Fault Detection					X	X			
	Accumulated Damage Analysis					X	X	X	X	
	Remaining Life Prediction					X	X	X	X	
	Probability of Failure Prediction					X	X			
	Life Cycle Management							X	X	

Notes:

End-use application	EPB - electric power, base load generation
	EPL - electric power, peaking operation
	AP - aircraft propulsion
	MD - mechanical equipment drive
	MP - marine propulsion
Time horizon	SR - less than 3 years
	MR - 3 to 7 years
	LR - 7+ years

APPENDIX D - GAS TURBINE USERS CONCERNS

User	Equipment Reported		Reported Concerns
	Unit Description	Quantity	
1	GE 7EA Peaking	2	GE 7EA - Highload compartment temperatures when ambient above 85 deg. F
	Pratt Whitney Twin Pak Peaking	1	PW C3- FT4 - Emissions Nox and CO
2	GE 5001N Peaking	48	Compressor hook fit failures
3	WE W501D24 Peaking	2	Starting reliability
	GE 5000 Peaking	1	Blade path spread control
	WE 301 Peaking	1	control air wetness
			Operator training/ proficiency
			starting motor/ sss clutch maintenance
4	2 WE W501F Daily Cycling	2	Hot Gas Path Parts Life in Cyclic Operation
			Combustor/ Transition Piece Life
			QA on Transition Piece repair (MTFIN Design)
			Combustor Dynamics and Proper Measurement thereof
			Hot Gas Path Parts Availability
5	GE 7EA Intermediate	3	Standard Combuster - GE7EA
			DLN GE 7EA
6	GE 7EA Peaking	15	Combustion Hardware and Wear Resistant Mods
			Exhaust Expansion Joints (cloth type)
			Fuel Oil Check Valves
			Sticking Servo and Moog Valves
			Exhaust Diffuser inner Horizontal Joint
7	WE W501B6 Baseload	2	Hot section component life
			Retrofits available for Nox reduction
			Improved inter- stage sealing of turbine for efficiency
			Power Augmentation advances
			HRSG Low Pressure section erosion/ corrosion control
8	ABB 11N2 Peaking	3	Combustor Inner Liner (ABB 11N2)
			Turbine Blades & Vanes (ABB 11N2)
			Fuel Oil Valve (ABB 11N2)
			Spare Parts (ABB 11N2)
9	GE 7EA Peaking	5	Cost Effective Installation of a fogging system on 7EA's
	P& W FT- 4 Peaking	120	Upgraded Control retrofits on FT- 4's using ETSI- INFI- 90 System has loop limitations (slow communications)
			Non- OEM Repair Facilities for Re- working 1st and/ or 2nd stage 7EA Rotor hubs
			On DLN- 1.0 &EA's - Muscle Air Compressors (Constant Corrective Maint. Issue)
10	GE 7C- STAG100 Intermediate	3	GE Frame 5 9th Stage Hook fit Cracking detection.
	GE 5N Peaking	3	Westinghouse W501AA compressor Stalls
	GE 7B Peaking	2	Westinghouse W501F Parts Life
	WE 501AA Peaking	6	GE 7F Parts Life
11	WE W501D5 Baseload	1	Blade Rock Correction Options - WE 501D5
	GE 7FA+ Baseload	1	Evaporative Cooling Effectiveness/ Problems
12	GE PG7121EA Simple	1	Determination of 7EA projected maintenance costs.
			Finding out what problems have been encountered during checkout/
			Obtaining the names of non- OEM QUALIFIED parts and or service providers.
			Feasibility of 7EA users pooling/ sharing spare parts.
13	GE 7001B Peaking	9	Compressor washing and methods - 7B
			Need the old version of EMAP 3.0
			GE rewinds of Generator 7B rotors - Failure of end turns?
			Problems with maintaing acceptable lube oil header temperatures during hot days (95+) - refurbishing oil cooler
14	GE 7FA Simple	2	HGP Parts
			Generator Life Cycle
			Controls & Instrumentation
15	GE 7001E Cycling - Base	4	W501D5 - Torque Converter/ Gear Box Assembly - Overhaul cycle frequency and qualified repair shops
	TP& M TP4- 2 Twin Pac Cycling	1	W501D5 -Unit Cool Down Sping Cycle - Procedures other than WE OMM- 64
	WE W501D5 Cycling - Base	2	W501D5 Lube Oil Pump Thrust Bearing - Expected service life and replacement upgrades
			W501D5 and GE7001E Exhaust Corrosion - partial replacement vs. complete replacements vs. material upgrades
			GE7001E - Generator #4 Bearing - Oil leak into generator, oil deflector seal install practices and housing joint seal compound
			GE7001E - boroscope equipment and inspection - consultant and equipment manufacturers
16	GE 7001EA Peaking	16	Kate's water injection control valves
			Lube oil leaks at #2 bearing drain coupling
			Purge check valves
			Generator lube oil leaks at bearing seals
17	18 GE 5LA, N, M Peaking	18	Spare parts for older Frame 5 Machines
	46 PW A4, A9, C1 C1D Peaking	46	Controls for older units (spare parts)
	7 GE 7A, B/ C, EA Peaking	7	
	6 EMD Peaking	6	
18	1 GE 7231FA Baseload	1	Combustor Dynamics of 501F
	2 WE W501F Cycle	2	Hot Gas Path Parts Life of 501F
			Generator Failures - 501F
			Combustor Tile Life & Failure Siemens 64.3A, 84.3A
			Inlet Fogging - GE7F
19	GE 7FA Baseload	1	Long Term Maintenance